NCHRP

Project No. NCHRP 9-44 A

Validating an Endurance Limit for HMA Pavements: Laboratory Experiment and Algorithm Development

Appendix 3

Project Lab Test Results Inserted into the Mechanistic Empirical Distress Prediction Models (M-E_DPM) Database

Prepared for

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
TRANSPORTATION RESEARCH BOARD
Of
The National Academies

Submitted by:

Matthew Witczak, Project P.I.
Michael Mamlouk, Project Co-P.I.
Mena Souliman, Research Assistant
Waleed Zeiada, Research Assistant

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INTRODUCTION

This appendix presents general information about the systematic recording of the major laboratory test data obtained from the lab experiments conducted in NCHRP Project 9-44A in a Microsoft Access® database named the Mechanistic-Empirical Distress Prediction Models (M-E_DPM) database, which was originally developed in NCHRP Project 9-30.

The major data groups that comprise the laboratory testing for NCHRP Project 9-44A are as follows:

1. HMA mix designs for three binder types: PG58-22, PG64-22, and PG76-16,
2. The weights of HMA loose mix loaded into the gyratory mold and the corresponding air voids of test specimens,
3. Binder test results including penetration-graded and performance-graded binder test results and Ai-VTSi relationships for the three binder types,
4. Dynamic modulus, phase angle, and E* master curve parameters,
5. Flexural beam fatigue results, and
6. Uniaxial tensile results including fingerprint tests.

The data recorded in the M-E_DPM database were developed by Arizona State University or AMEC Inc. (formerly MACTEC). Data input was accomplished by Arizona State University staff under the general guidance of a senior engineer from AMEC Inc.

The following sections provide detailed information on the items input for each of the major group noted above.

DATABASE DEVELOPMENT FOR NCHRP PROJECT 9-44A

The M-E_DPM database is coded in Microsoft Access® to provide a hierarchical database structure for storing pavement and materials information collected from major pavement sites (e.g., LTPP, WesTrack, MnRoad, NCAT, etc.). The database was developed to be mainly used for the future refinement, calibration, and validation of the HMA mechanic-empirical distress prediction models incorporated in the AASHTOWare Pavement ME Design program.

The objective of this database development in NCHRP Project 9-44A was to enhance this capability for future distress model calibration and validation, by adding the comprehensive laboratory experimental results obtained in the project.

Database Structure

The major tables in the program are shown on the left side of **Figure 1**. When it is opened (by a double click), the table illustrates specific information such as general, layer structure, material properties, distresses, units, etc. It is important to note that some tables are programmed to effectively connect with each other (i.e., any information displayed in a table can be found in other connected tables), and therefore, the user can use any of these tables for inputting or retrieving data. Of those tables, the "CAL_Sections" table was designed to display the major project sites. Also, under this table, it was possible to add or create a new project section. The following three major categories were created under the table to input test results by binder performance grade:

- Arizona State Univ. (PG 58-28)
- Arizona State Univ. (PG 64-22)
- Arizona State Univ. (PG 76-16)

In the middle of **Figure 1**, a screenshot of the program shows the three category rows that were created.

The database is uniquely structured with multiple hierarchical levels. The user can expand or collapse the individual category section by clicking on a cell button beside each of the section ID cells. In **Figure 1**, each of the three Arizona State University categories can be expanded under each new sub-category or groups that were created.

It should be noted that this sub-group section was originally developed for inputting pavement layers from surface to subgrade. For each layer, another low level category can be created where the layer information is stored such as a thickness, volumetrics, etc. For the NCHRP Project 9-44A database development; the data to be placed into the database from the Arizona State University testing program were not from an actual pavement layer, but from laboratory experiments. As a result, several major laboratory test categories were created. The following lower level categories were created under each of the Arizona State University section IDs:

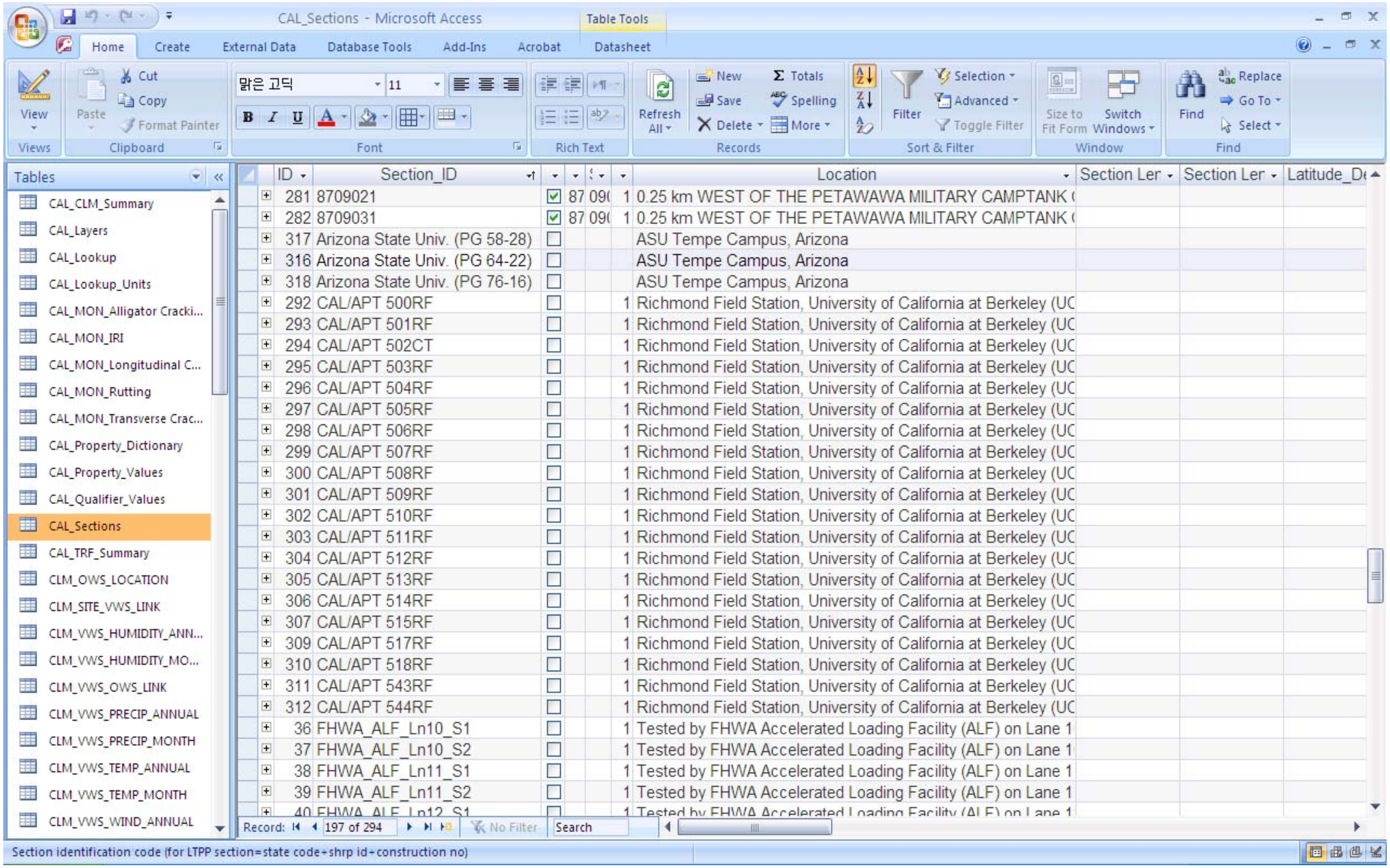

Figure 1 Screenshot of the Database: ASU Section IDs under the “CAL_Sections” Table

ASU Section ID: Arizona State Univ. (PG 58-28)

- HMA (Mix Design)
- HMA (Binder Testing, PAV)
- HMA (Binder Testing, RTFO)
- HMA (Binder Testing, PAV)
- HMA (E*, PG58-28, AC 4.2%, VA 9.5%)
- HMA (E*, PG58-28, AC 4.2%, VA 7.0%)
- HMA (E*, PG58-28, AC 4.2%, VA 4.5%)
- HMA (E*, PG58-28, AC 4.7%, VA 9.5%)
- HMA (E*, PG58-28, AC 4.7%, VA 7.0%)
- HMA (E*, PG58-28, AC 4.7%, VA 4.5%)
- HMA (E*, PG58-28, AC 5.2%, VA 9.5%)
- HMA (E*, PG58-28, AC 5.2%, VA 7.0%)
- HMA (E*, PG58-28, AC 5.2%, VA 4.5%)
- HMA (Beam Fatigue, PG 58-28, AC 4.2%, VA 4.5%)
- HMA (Beam Fatigue, PG 58-28, AC 4.2%, VA 9.5%)
- HMA (Beam Fatigue, PG 58-28, AC 5.2%, VA 4.5%)
- HMA (Beam Fatigue, PG 58-28, AC 5.2%, VA 9.5%)

- ASU Section ID: Arizona State Univ. (PG 64-22)
  - *The same items as the PG 58-28 category (from Mix Design to Beam Fatigue)*
  - HMA (Fingerprint Test, PG 64-22, AC 4.2%, VA 4.5%)
  - HMA (Fingerprint Test, PG 64-22, AC 5.2%, VA 4.5%)
  - HMA (Fingerprint Test, PG 64-22, AC 4.2%, VA 9.5%)
  - HMA (Fingerprint Test, PG 64-22, AC 5.2%, VA 9.5%)
  - HMA (Uniaxial Fatigue, PG 64-22, AC 4.2%, VA 4.5%)
  - HMA (Uniaxial Fatigue, PG 64-22, AC 5.2%, VA 4.5%)
  - HMA (Uniaxial Fatigue, PG 64-22, AC 4.2%, VA 9.5%)
  - HMA (Uniaxial Fatigue, PG 64-22, AC 5.2%, VA 9.5%)

- ASU Section ID: Arizona State Univ. (PG 76-16)
  - *The same items as the PG 58-28 category (from Mix Design to Beam Fatigue)*

There are five major data groups under the PG 58-28 and PG 76-16 binders: mix design, binder testing, E*, beam fatigue, and the relationship between specimen air voids and mass of loose HMA mix. For the PG 64-22 binder, in particular, in addition to these five groups, there are two additional groups: finger print and uniaxial fatigue. These two categories are the major outputs from the uniaxial testing. It should be recognized that under each of the major test result group (i.e., mix design, binder testing, E*, beam fatigue, air voids–mass, fingerprint, and uniaxial fatigue), lower level groups are subsequently placed and each of the lower level group contains detailed test results. This information is explained in the following sections. Figure 2 shows a screenshot of the database containing the major data groups.

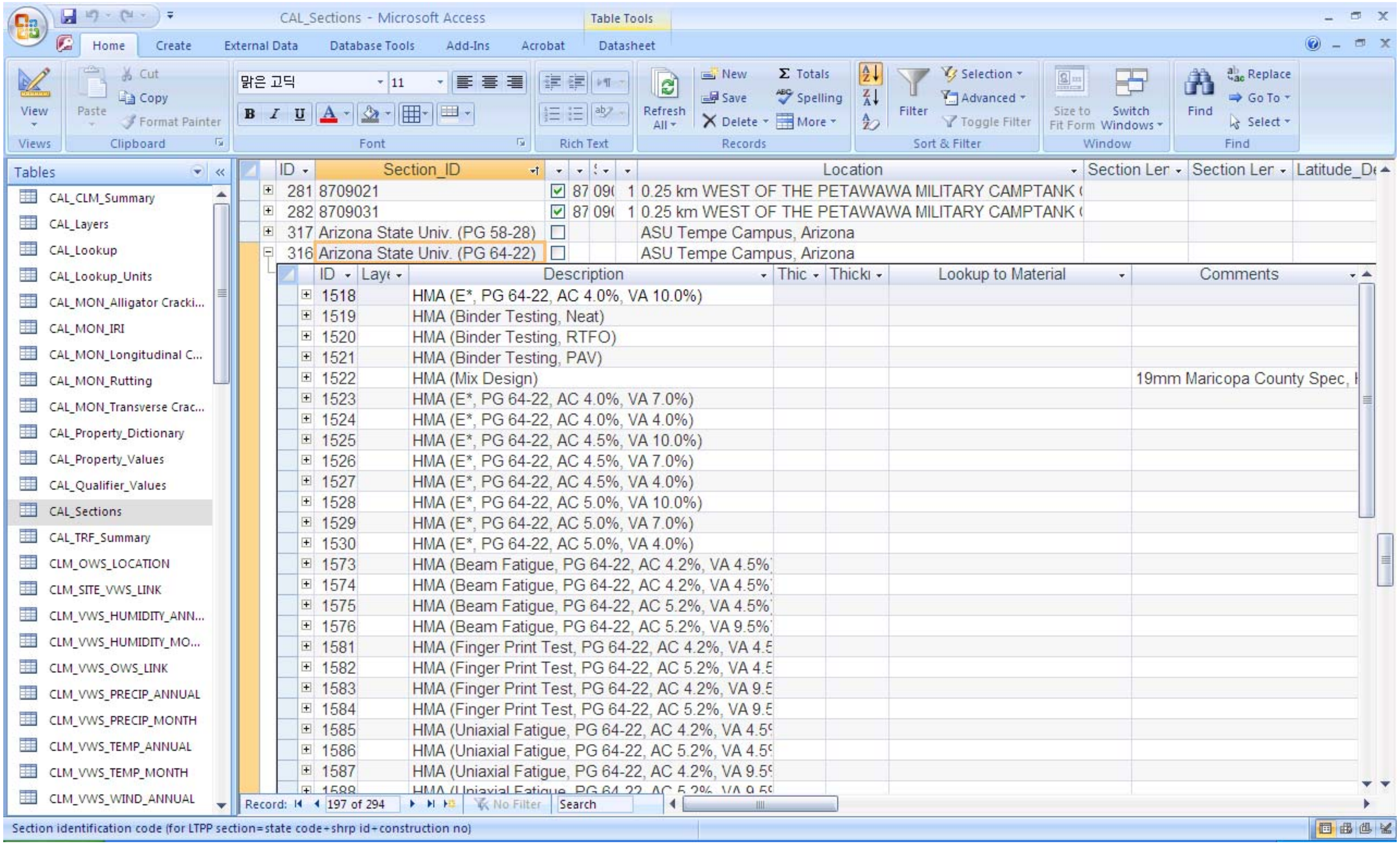

Figure 2 Screenshot of the Database: Hierarchical Structure

Mix Design Data Input

The mix designs of each of the asphalt binder types (three PG binder types) used for the project were summarized from MACTEC reports completed in the early stages of the project. Key properties of the mix design were input and stored in the database. The following properties, in alphabetical order, are displayed in the database; a screenshot of the database program showing these properties is presented in **Figure 3**:

- Air Voids (Design)
- Asphalt Absorption into Dry Aggregate
- Asphalt Content by Weight
- Binder Grade (PG)
- Bulk Specific Gravity (Combined Aggregate)
- Bulk Specific Gravity of Coarse Aggregate
- Bulk Specific Gravity of Fine Aggregate
- Bulk Specific Gravity of HMA Mix
- Compaction Temperature
- Dust to Effective Asphalt Ratio
- Film Thickness
- Flat and Elongate of Aggregate
- Fractured Face One
- Fractured Face Two
- LA Abrasion at 500 Rev
- Max Specific Gravity of HMA Mix
- Mixing Temperature
- Passing 0.075mm
- Passing 0.15mm
- Passing 0.30mm
- Passing 0.475mm
- Passing 0.60mm
- Passing 1.18mm
- Passing 12.5mm
- Passing 19.0mm
- Passing 2.0mm
- Passing 2.36mm
- Passing 25.0mm
- Passing 31.3mm
- Passing 37.5mm
- Passing 4.75mm
- Passing 6.3mm

- Passing 9.5mm
- Sand Equivalent
- Specific Gravity of HMA Binder
- Tensile Strength Ratio
- Uncompacted Voids
- Voids Filled with Asphalt (VFA)
- Voids in Mineral Aggregate (VMA)
- Water Absorption of Combined Aggregates

Asphalt Binder Test Results

The asphalt binder test results were input into the database. These data include the penetration-graded (penetration and softening point) and performance-graded binder (Brookfield Viscosity) test results for the three PG binder types. For each binder type, test results were obtained under three specific aging conditions: original or neat condition, short-term aged condition (RTFO), and long-term aged condition (PAV). The binder data also include the test temperature and calculated viscosity. The temperature is recorded in three different units: degrees Fahrenheit, degrees Celsius, and degrees Rankine (used in computing the binder Ai - VTSi value). The viscosity values are expressed in centipoises.

The regression parameters (Ai and VTSi) computed from the temperature-viscosity relationship for each binder type were also entered into the database, using the temperature in degrees Rankine and viscosity in centipoise.

The following list shows the input items of the database; a database screenshot showing these items is presented in **Figure 4**. Since all binder testing was conducted in replicate over a wide range of test conditions, multiple rows were created with the same property name where the test condition and resulting values are unique for each row of the database.

- Ai (Intercept of the viscosity – temperature relationship)
- VTSi (Slope of the viscosity – temperature relationship)
- Binder Grade (PG)
- Penetration
  - Age (Neat or RTFO or PAV)
  - Temperature in deg. Celsius
  - Temperature in deg. Fahrenheit
  - Temperature in deg. Rankine
  - Temperature in deg. Rankine (Log value)
  - Viscosity in Centipoise
  - Viscosity in Centipoise (Log Log value)

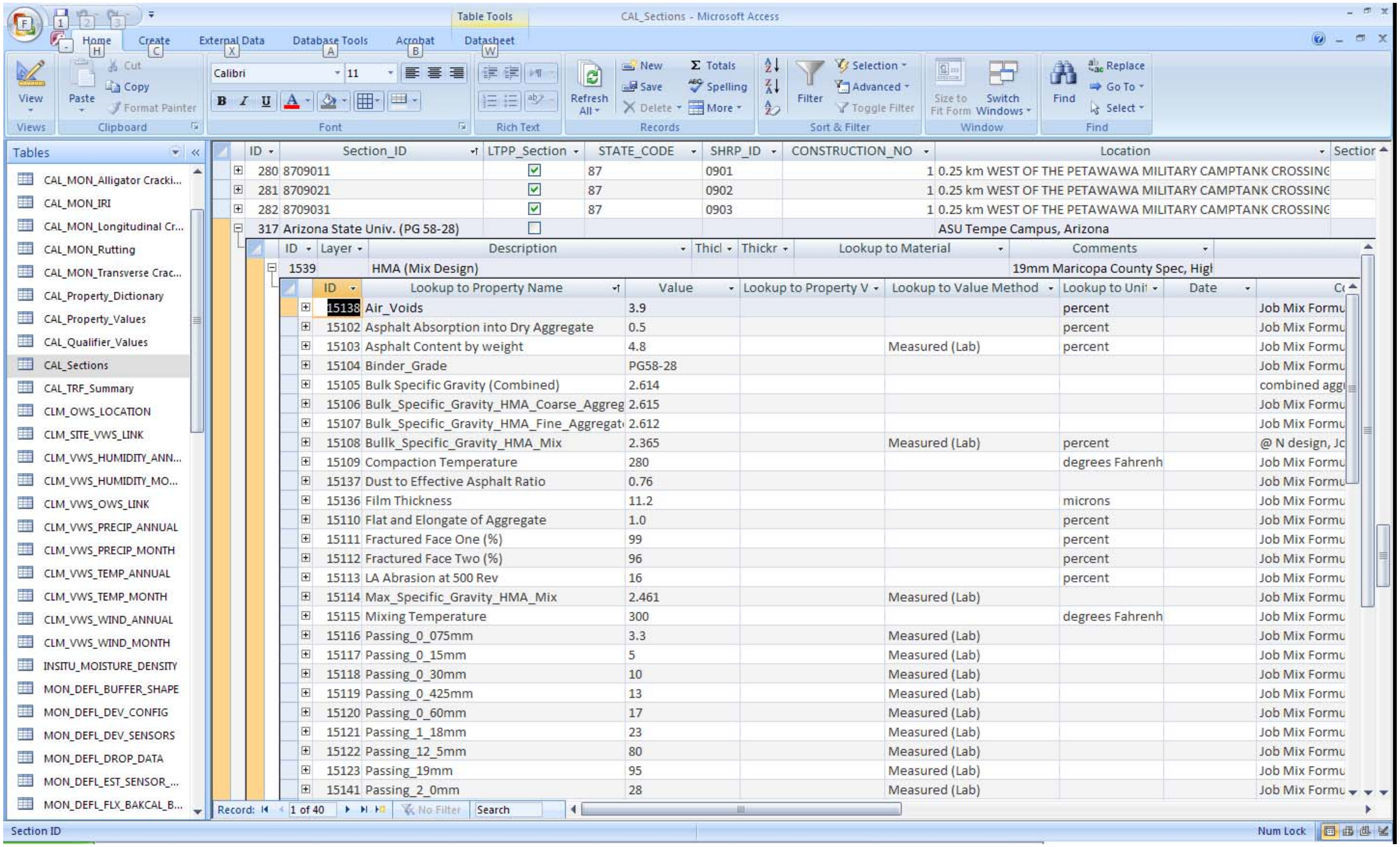

Figure 3 Screenshot of the Database: Mix Design Data Input

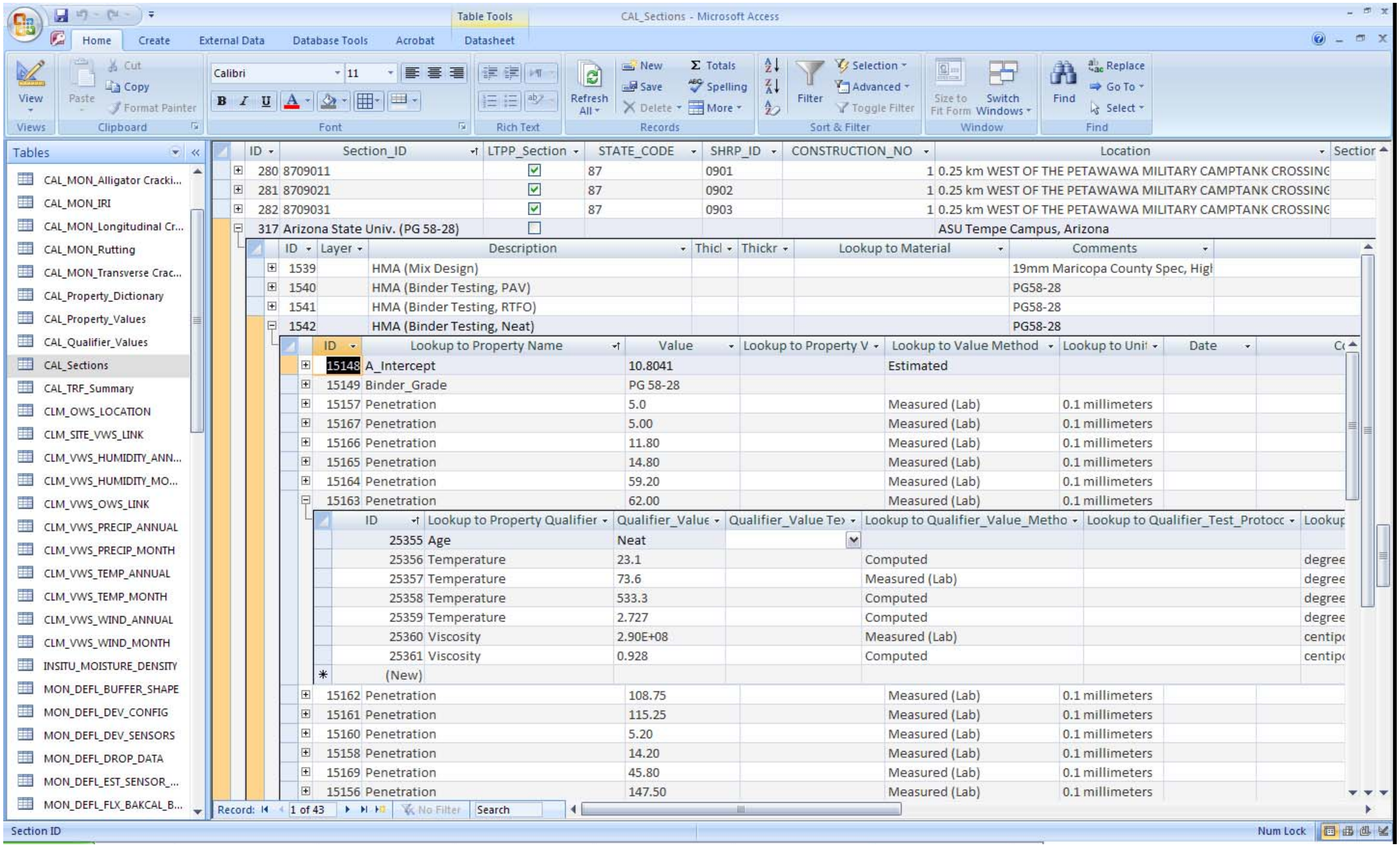

Figure 4 Screenshot of the Database: Binder Test Results Input

- Softening Point
    - Age (Neat or RTFO or PAV)
    - Viscosity in Centipoise (Log Log value)
- Brookfield
    - Age (Neat or RTFO or PAV)
    - Viscosity in Centipoise (Log Log value)

Dynamic Modulus Test Results

The dynamic modulus (E*) test results obtained at Arizona State University were also incorporated into the database. Similar to the other tests, E* tests were performed with the specimens manufactured with the three performance-graded binders. Therefore, under each of the main ASU section IDs shown in the previous section; the detailed test results were inputted. The properties included in the database are as follows; a screenshot showing the inputs is presented in **Figure 5**:

- Dynamic Modulus (E* values at each test temperature – frequency combinations)
    - Temperature in deg. Fahrenheit
    - Frequency in Hz
    - Standard Deviation
    - Coefficient of Variation

- Phase Angle (phase angle at each test temperature-frequency combinations)
    - Temperature in deg. Fahrenheit
    - Frequency in Hz
    - Standard Deviation
    - Coefficient of Variation

- E* Master Curve parameters
    - Alpha
    - Beta
    - Gamma
    - Delta
    - a (time-temperature shift function coefficient for the regression model)
    - b (time-temperature shift function coefficient for the regression model)
    - c (time-temperature shift function coefficient for the regression model)

Beam Fatigue Test Results

Over 450 test specimens were manufactured and tested for the flexible beam fatigue behavior study at Arizona State University. The experimental test conditions included three levels of

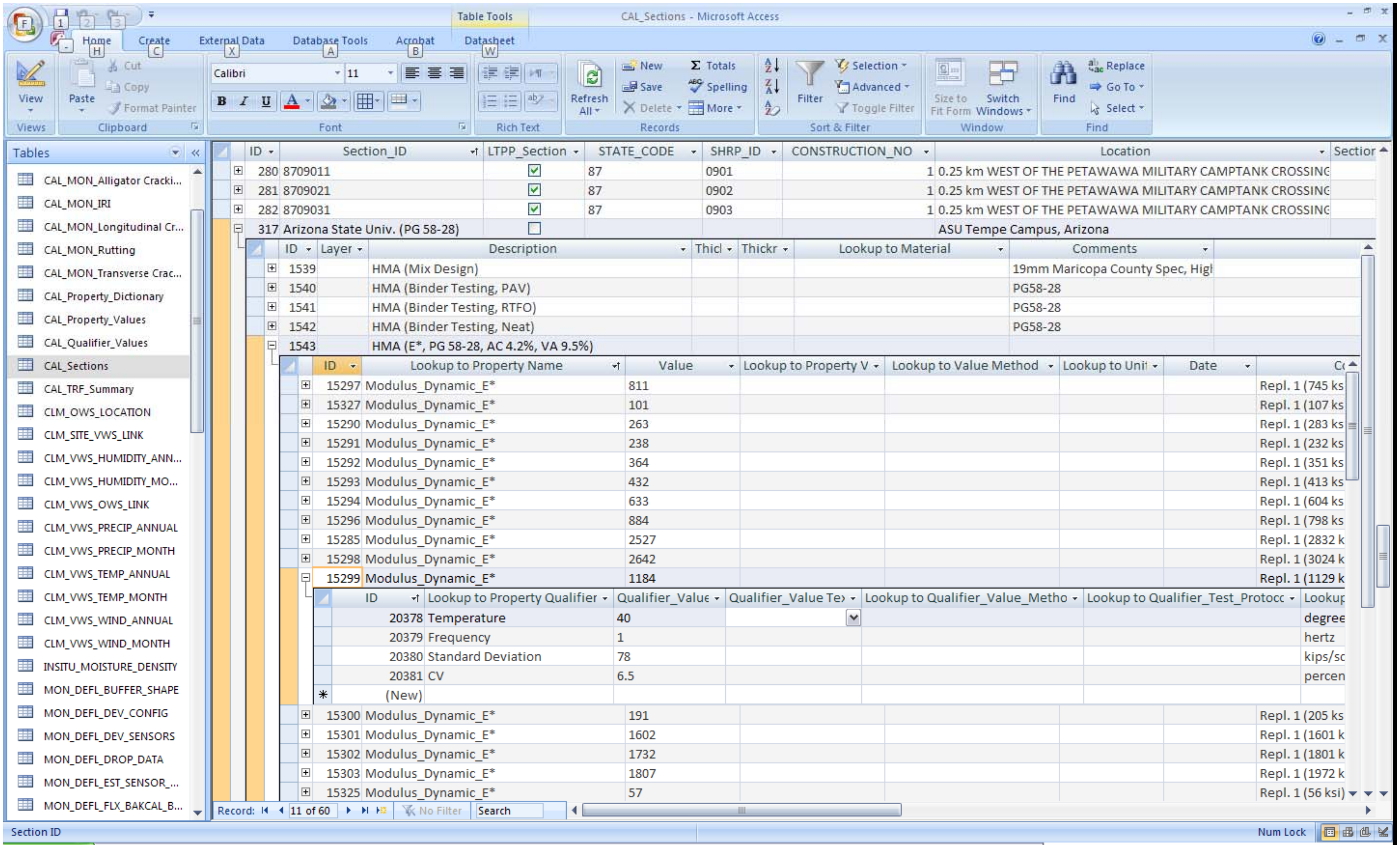

Figure 5 Screenshot of the Database: E* Test Results Input

temperature (40, 70 and 100°F), three levels of binder type (PG 58-22, PG 64-22, and PG 76-16), two levels of asphalt content (4.2 and 5.2%), and two levels of air voids (4.5 and 9.5%). With these variable levels, the following four major categories were established for each binder type for systematic input of the test data:

- HMA (Beam Fatigue, AC 4.2%, VA 4.5%)
- HMA (Beam Fatigue, AC 4.2%, VA 9.5%)
- HMA (Beam Fatigue, AC 5.2%, VA 4.5%)
- HMA (Beam Fatigue, AC 5.2%, VA 9.5%)

In each of these major categories, the two major beam fatigue test were recorded: Number of Cycles to Beam Fatigue and Stiffness Ratio. Each of these properties is characterized by several test parameters, which are also recorded in the database, as follows:

- Number of Cycles to Beam Fatigue
    - Strain
    - Stress
    - Initial Stiffness
    - Rest Period
    - Test Temperature
- Stiffness Ratio
    - Strain
    - Stress
    - Initial Stiffness
    - Rest Period
    - Test Temperature
    - Number of Cycles

Further, there are numerous test replicates with the same asphalt content and air voids. As a result, under the same air voids – asphalt content category, several replicate properties are found as shown in **Figure 6**. Note that the specimen (replicate) IDs are displayed at the end of each row.

Uniaxial Test Results

The last major laboratory test conducted by Arizona State University was the uniaxial test. This category of testing was only completed for the PG-64 binder mixtures. Two major test categories were obtained for the test: fingerprint and uniaxial fatigue. These data were organized in the same 2x2 matrix as that established for the beam fatigue test with two levels of air voids (4.5 and 9.5%) and two levels of asphalt contents (4.2 and 5.2%):

- HMA (Fingerprint Test, AC 4.2%, VA 4.5%)
- HMA (Fingerprint Test, AC 4.2%, VA 9.5%)

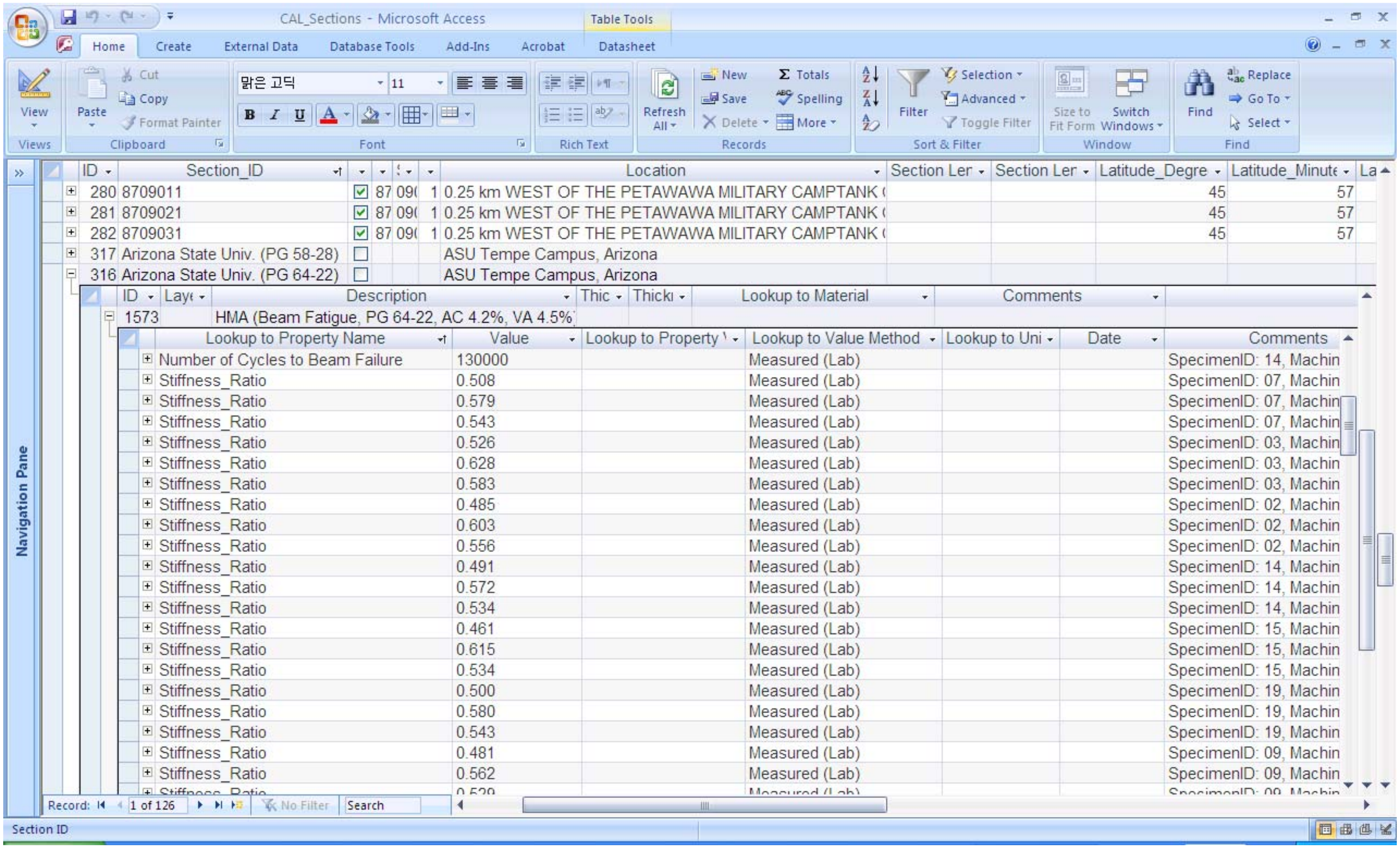

Figure 6 Screenshot of the Database: Beam Fatigue Test Results Input

- HMA (Fingerprint Test, AC 5.2%, VA 4.5%)
- HMA (Fingerprint Test, AC 5.2%, VA 9.5%)
- HMA (Uniaxial Fatigue, AC 4.2%, VA 4.5%)
- HMA (Uniaxial Fatigue, AC 4.2%, VA 9.5%)
- HMA (Uniaxial Fatigue, AC 5.2%, VA 4.5%)
- HMA (Uniaxial Fatigue, AC 5.2%, VA 9.5%)

Three major properties were recorded for the fingerprint test: Machine Compliance Factor, Fingerprint Modulus, and Phase Angle. Two major properties were recorded for the uniaxial fatigue test: Number of Cycles to Failure and Pseudo Stiffness Ratio. The related test conditions were also recorded in the database for each property. These are summarized as follows; a screenshot is presented in **Figure 7**:

- Machine Compliance Factor
    - Actual Air Voids measured for Test Specimen
    - Temperature
    - Strain
    - Rest Period

- Fingerprint Modulus
    - Actual Air Voids measured for Test Specimen
    - Temperature
    - Strain
    - Rest Period

- Phase Angle
    - Actual Air Voids measured for Test Specimen
    - Temperature
    - Strain
    - Rest Period

- Number of Cycles to Failure
    - Actual Air Voids measured for Test Specimen
    - Temperature
    - Strain
    - Rest Period
    - Initial Stiffness
    - Initial Tensile Stress
- Number of Cycles

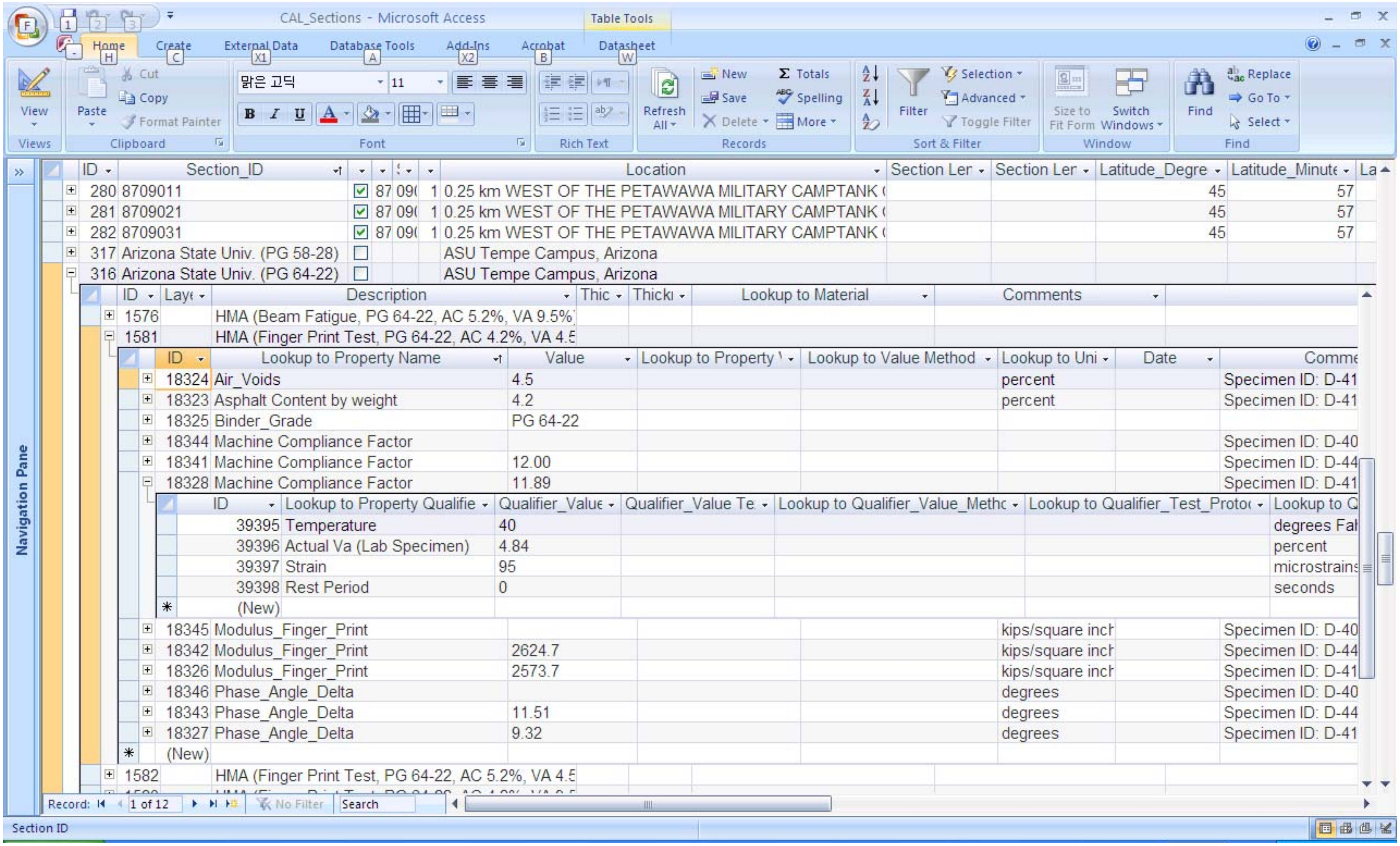

Figure 7 Screenshot of the Database: Uniaxial Results Input

- Pseudo Stiffness Ratio
    - Actual Air Voids measured for Test Specimen
    - Temperature
    - Strain
    - Rest Period
    - Initial Stiffness
    - Initial Tensile Stress
    - Number of Cycles

Specimen Air Voids and Mass of Molded Loose HMA Mix Data

The test specimens used for E* testing conducted at Arizona State University were prepared based on the relationships between mass and air voids. The mass in this context is defined as an amount (weight) of loose asphalt mix placed into the Superpave gyratory mold; the air voids represent the actual air voids calculated from the G_{mm} and G_{mb} values of the test specimens. For each binder type, three different levels of HMA mass were used. The same weights were applied to each binder content level and the corresponding air voids of each specimen were measured. Therefore, the matrix of three levels of the asphalt contents and three actual air void levels for each binder content level were created in the database.

Figure 8 shows a screenshot of the M-E_DPM database program for PG 58-28. There are nine categories (three binder content levels by three actual air voids level). Under each category, the following mix information was recorded:

- Actual Air Voids measured for Test Specimen
- Loose Mix Weight into the Gyratory Mold
- Asphalt Content by Weight
- Bulk Specific Gravity of HMA Mix (G_{mb})
- Theoretical Maximum Specific Gravity of HMA Mix (G_{mm})

Summary

The M-E_DPM database program, originally developed under NCHRP Project 9-30, has been expanded by adding the laboratory test results obtained from NCHRP Project 9-44A conducted at Arizona State University. The purpose of the program was to provide a hierarchical database structure for storing pavement and materials information collected from major pavement sites. The database was developed to be mainly used for the future refinement, calibration, and validation of the HMA mechanic-empirical distress prediction models incorporated in the AASHTOWare Pavement ME Design program.

The objective of this database's development under NCHRP 9-44A was to enhance the current version of the M-E_DPM database program and maximize the capability for its potential use in the distress model calibration and validation. This was accomplished by adding the comprehensive laboratory experiment results extensively conducted at Arizona State University during NCHRP Project 9-44A. The major tests conducted by Arizona State University were:

- HMA Mix Designs for three binder types: PG58-22, PG64-22, and PG76-16
- Binder test results including conventional and Superpave binder test results and Ai-VTSi relationships for the three binder types
- Dynamic modulus, phase angle, and E* Master Curve parameters
- Flexural beam fatigue results
- Uniaxial tensile results including fingerprint test
- Air voids and mass of loose HMA mix into mold

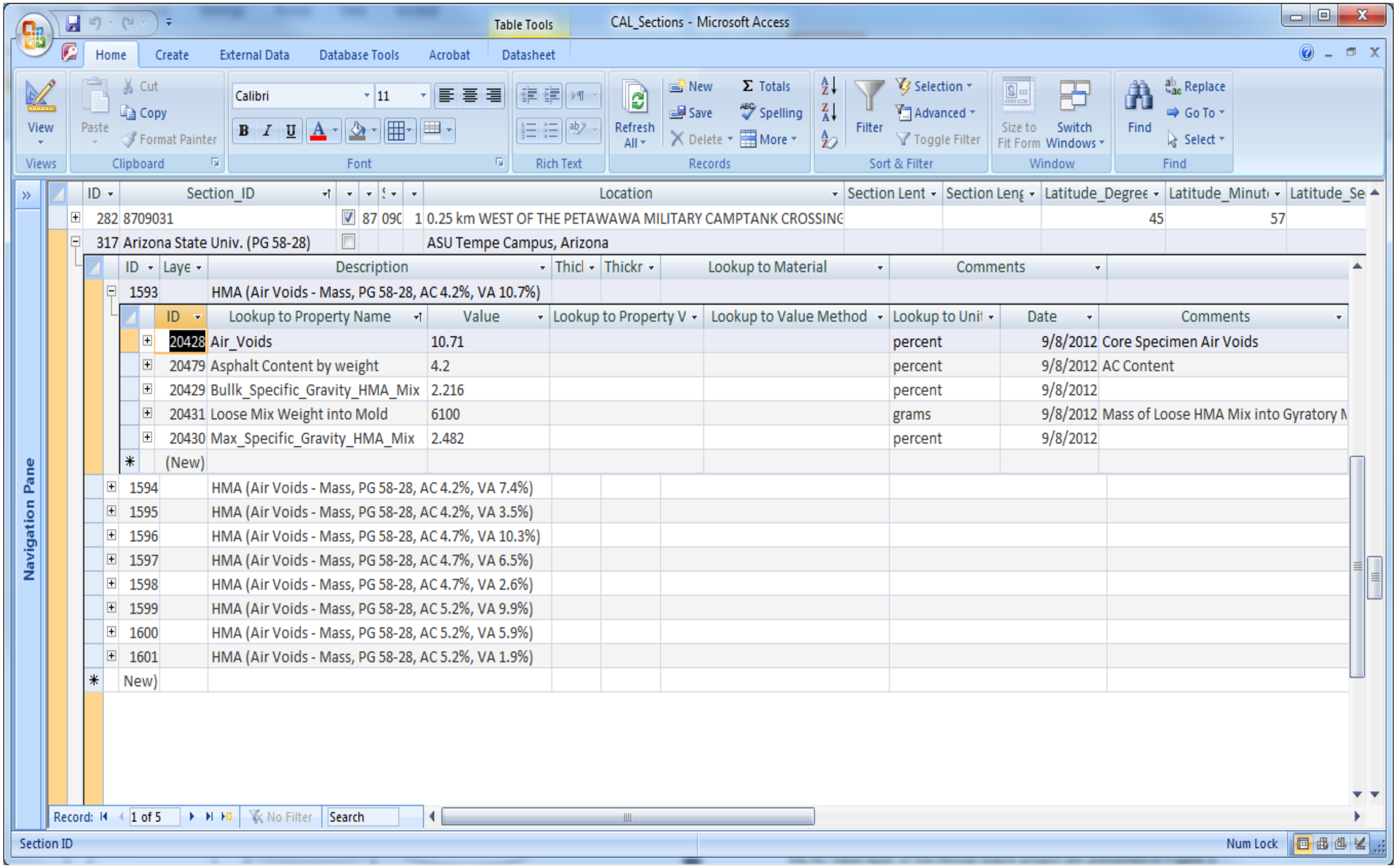

Figure 8 Screenshot of the Database: Air Voids-Mass Data Input